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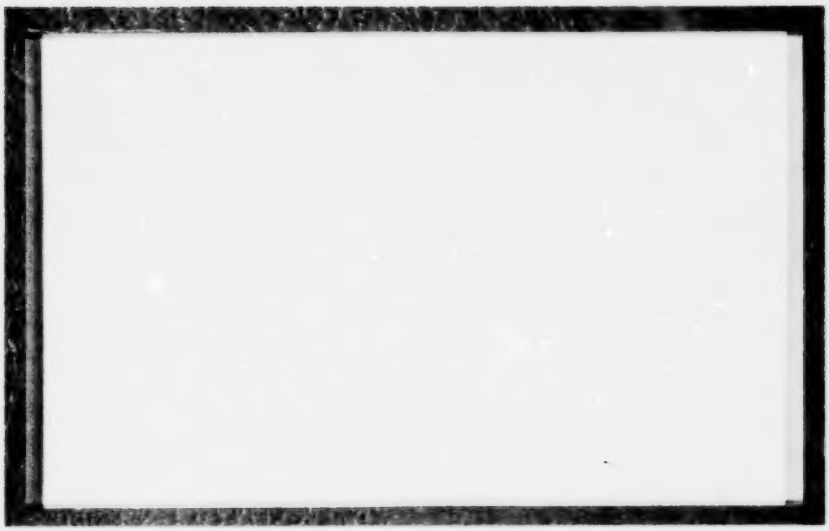

CENTRE DE RECHERCHE SUR LES TRANSPORTS

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A DECOMPOSITION APPROACH FOR REHABILITATION AND MAINTENANCE PROGRAMMING

by

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ABSTRACT

This paper presents a general approach for the optimal planning over a middle to long-term horizon of pavement maintenance and rehabilitation investments for large highway networks divided into a number of regions and districts. In this approach, the overall planning problem is decomposed into two smaller problems: a strategic planning problem, in which one seeks at network level to establish priorities, budgets, and performance objectives for the regions or districts, and a tactical planning problem in which a good feasible (with regard to the priorities, budgets, and objectives established at network level, and to various local constraints) maintenance and rehabilitation program is determined separately for each region or district by the local authorities of such regions or districts.

The technical (from a modeling and computing standpoint) and organizational advantages of this approach over previous ones are discussed, as well as some of the difficulties arising from the need to interface the models used for solving the two smaller problems.

The method is illustrated by suggesting a possible choice of models for the strategic and the tactical planning problems.

Key words : optimization, programming, rehabilitation, maintenance, large networks, decomposition.

RÉSUMÉ

Nous présentons une approche générale pour la planification à moyen et long terme des interventions d'entretien et de réhabilitation sur un réseau routier de grande taille divisé en un certain nombre de régions ou districts. Dans cette approche, le problème global de planification est décomposé en deux problèmes de taille moindre : un problème de planification stratégique, dans lequel on cherche à établir des priorités, des budgets et des objectifs de performance pour les régions ou districts en considérant le réseau dans son ensemble, et un problème de planification tactique, dans lequel on cherche à déterminer au niveau de chaque région ou district un programme d'intervention réalisable respectant les budgets, priorités et objectifs établis au niveau stratégique, ainsi que les contraintes et préoccupations existant au niveau local.

Mots-clés : réseaux routiers, entretien, réhabilitation, programmation, décomposition.

1. Introduction

In this paper, we address, in a very general form, the problem of the optimal planning of pavement maintenance and rehabilitation investments for a large highway network over a middle to long-term planning horizon. In the past, this problem has usually been formulated, explicitly or implicitly, as a large optimization problem encompassing the whole network at hand. While this approach might look very attractive at first glance, it is not totally satisfactory for two main reasons:

1) with the current state of modeling and computing technology, it does not seem possible, when one has to deal with a large network, to truly optimize the selection of investment decisions over the range of all possible alternatives, if the subtle interactions which exist between potential projects are to be taken into account;

2) a single global optimization model cannot properly reflect the distributed nature of the decision-process involved in maintenance and rehabilitation programming for a large network, divided into a number of regions or districts.

To circumvent these difficulties, we propose a new general approach in which the overall planning problem is decomposed into two smaller problems: a strategic planning problem, in which one seeks at network level to establish priorities, budgets, and performance objectives for the regions or districts, and a tactical planning problem, in which a good feasible (with regard to the priorities, budgets, and objectives established at network level, and to local constraints) program is determined separately by the local authorities of such regions or districts.

This new approach appears to be very promising, since it allows the decision-makers at various levels of an agency to focus on the elements of

the problem which are of direct concern to them: global picture of the network for the central planners and detailed information for the local staff of the agency subdivisions.

The remainder of this paper is mainly devoted to a discussion of the advantages and disadvantages of the proposed methodology and to a sample illustration of it. It is organized as follows:

- the overall problem addressed is carefully defined in section 2;
- in section 3, some estimates of problem size for a detailed global optimization formulation are given;
- section 4 is devoted to a short review of some of the models which have been proposed in the past for the problem;
- the decomposition approach is described in detail in section 5;
- in section 6, the advantages of the approach from a technical and from an organizational standpoint are discussed;
- some of the difficulties arising from the need to interface the models used for strategic and tactical planning are presented in section 7;
- in section 8, the approach is illustrated by describing a possible implementation;
- section 9 concludes the paper.

2. The Planning Optimization Problem

The objective of this section is not to define extensively what is generally meant by the optimal planning of pavement maintenance and rehabilitation investments, but rather to make precise the assumptions under which the decomposition approach is proposed. These assumptions are:

1) the network for which the planning is to be done is large, i.e., it consists of thousands (possibly tens of thousands) of pavement sections and it is divided into a fair number (say 10 to 50) of regions or districts in which local staff has been up to now partially responsible of the condition of the subnetwork under its jurisdiction;

2) the agency managing the network has decided upon using some kind of dynamic optimization procedure with a planning horizon of the order of 5 to 10 years (periods);

3) the optimization procedure is to cover both the maintenance (particularly preventive maintenance) and the rehabilitation aspects of pavement management, thus making it necessary to allow for multiple interventions on any given section within the planning horizon;

4) there might be cost interactions between projects, such as economies of scale when contiguous sections are maintained or rehabilitated at the same time;

5) apart from the selection and sequencing of projects, other decision variables (e.g. location of asphalt plants) might have to be determined;

6) various local constraints might have to be taken into account in the optimization procedure.

It should be noted here that no assumptions were made regarding: the nature of the optimization to be carried out, i.e. whether one wants to minimize budget requirements to attain a specified network performance or to maximize the utility of the network for a fixed set of budgets; the specific elements to be included in the objective function and the constraints (user costs, agency costs only, bounds on pavement condition, salvage values, etc.); the type of model desired (deterministic or probabilistic); the mathematical model and solution technique used. These factors have no direct impact on the relevancy of the decomposition approach.

3. Size Estimates for a Single Detailed Optimization Model

We shall now try to give some idea of the tremendous size of any detailed mathematical formulation of the planning optimization problem under the assumptions of the previous section.

Let us consider first the number of decision variables. In our opinion, it is not possible in a detailed formulation not to treat individual pavement sections as separate entities. For a network with N sections and a planning horizon of T years, if there are on the average R possible treatments for each section in each year, this implies that there are at least N·R·T decision variables (some formulations would have a lot more). As an example, one should note that for N=2000, T=5, and R=5, N·R·T=50,000, which is quite an impressive number. But this is not the worst part of it. Dealing with the interactions between projects is much more difficult. In an integer programming formulation, the simplest interactions (interactions between pairs of projects) would require cross-product terms in the decision variables, the number of which could easily run in the millions or more. In a dynamic programming formulation, some of the interactions could be more easily taken care of, but this would necessitate the introduction of condition states at each period for each section and the number of decision variables would then be multiplied by 3 or 4 at least, thus making the program intractable for all practical purposes. Adding local constraints or other decision variables would only aggravate the matter.

From what precedes, it should now be obvious that size problems are such that using a single detailed optimization model is not a practical alternative under the stated assumptions.

4. Review of some previous work

It is not our intention, in this section, to present an exhaustive survey of the optimization models which have been developed for maintenance and rehabilitation programming; such an endeavor would deserve a much

lengthier treatment than is possible here. We will however try to sketch a rough picture of the current state-of-the-art regarding such models.

Over the last ten years or so, a fair number of dynamic optimization models for pavement management have been proposed and many of these have been used by agencies responsible for large highway networks. This may look surprising in the light of the conclusions of the preceding section. Careful analysis shows however that those models have all been designed so as to cut down on problem size in order to make it tractable.

One of the easiest ways of achieving such an end is to limit the range of alternatives to be considered in the optimization process for each pavement section. This is usually done by some kind of pre-optimization procedure which retains only the most attractive treatments for each section [1,3,5,7]. Moreover, in some models [1,3], apart from routine maintenance, only one treatment can be performed on any given section over the length of the planning horizon. To further cut down on solution times, many authors [2,3,4,6] have used near-optimization (heuristic) methods rather than exact optimization procedures. It should be noted that, in all those models, there is no provision for project interactions (for adjacent pavement sections) and that treatment interaction (for any given section) is either neglected or very limited (in some models, it is impossible).

A radically different approach was used to reduce problem size in the Network Optimization System of the state of Arizona [8,9]. Aggregation (grouping) of the pavement sections relative to their "condition" made it possible to represent the whole network using only 120 "states". This led naturally to a Markov Decision Process formulation which could easily be solved exactly by linear programming software. This model (when properly calibrated) provides a fine global "picture" of a network and of its evolution through time, but there is a price to be paid for this: the loss of identity of the individual pavement sections. An obvious consequence of

this is the absolute impossibility of accounting for cost interactions between projects and for other dimensions of the problem related to the geographical location of the sections. Apart from those, some other subtle difficulties stemming from the aggregation process might be encountered when using this model.

In summary, one may say that this brief review confirms the conclusions of section 3: for a global optimization model to be tractable, some of the finer details of the overall "picture" must be "sacrificed" one way or the other.

5. The Decomposition Approach

The aim of any optimization model is fundamentally decision-support. When considering the development of an optimization model for pavement management, it is thus very important to determine who the users of the model will be and the nature of the decision process to be supported. In large agencies, there are several levels of decision-making and the specific issues of interest are bound to be different for decision-makers at various levels. As pointed out by Kher and Cook [5], what management needs for proper funding decision making is comprehensively information on project strategies and the way in which those strategies relate to system health. For instance, many planners "prefer to think of the quality of pavement in terms of the percentage of pavements lying in each adequacy class" [5, p. 6.36]. On the other hand, at field level, there is no need for aggregation, but rather for precise and detailed information and decisions.

Obviously, one could try to answer those conflicting needs within a single model, but it seems preferable to divide the overall planning problem into two parts: a strategic planning problem and a tactical planning problem.

The strategic planning problem addresses the preoccupations of management at network level. The focus here is not on individual pavement sections, but rather on the overall condition of the network and on policy issues. This problem is thus stated using aggregated information and decision variables. A major output is an allocation of funds to districts or regions along with performance objectives to be met by these.

In the tactical planning problem, which can be solved separately for each region or district, the goal is the determination of the best local maintenance and rehabilitation program possible, taking into account as much as feasible the various interactions between projects. A fundamental input to this problem is the set of budgets and performance objectives determined at network level for the region or district.

6. Advantages of the Decomposition Approach

Apart from its better focus as decision-support tool, the decomposition approach possesses technical and organizational advantages over previous models.

If we compare the decomposition approach to other models in which pavement sections are not aggregated on the basis of the computing effort required, we can note that instead of solving a large optimization problem on a network of N sections, we have to solve a strategic planning problem (which should be fairly small due to the aggregation) and, if we suppose that we have M regions, M tactical planning problems on networks make up of N/M sections on the average. For most optimization models, the running time is not linear in the size of problem; in general, it will tend to grow much faster than the number of sections considered. It is thus much cheaper in general to solve M problems of size (N/M) than to solve a single problem of size M. This advantage may be compounded by the fact that, for a given planning horizon T, while it is necessary to solve the strategic planning

problem using this horizon, it is quite conceivable that the tactical planning problems could be solved using a shorter planning horizon, thus precipitating a further reduction in computing time.

Another advantage of using decomposition is that, since the networks that are considered in tactical planning are much smaller than the whole network, it might become possible to use techniques such as interactive graphics methods in which the network is displayed on a computer terminal screen, while this is infeasible for the whole network.

On the organizational side, decomposition explicitly takes into account the existence of various levels of decision-making. This should make it more acceptable to lower levels of the hierarchy than a method which relies on a single optimization model run by the planning staff of the head office. With such a model, there is always the danger that hypercentralization will result, thus provoking severe strains in the organization.

7. Disadvantages of the Decomposition Approach

The main disadvantages of the decomposition approach relatively to single model approaches are that it requires the development of two models (an aggregated model for tactical planning and a detailed model for tactical planning) and that these models must be consistent in order to form an integrated planning system. Regarding that consistency issue, it should first be stressed that the aggregated information used by the strategic planning model must be carefully derived from the detailed information used in tactical planning or otherwise disasters will probably occur. Aside from this data consistency, there should also be some kind of logical consistency or "compatibility" between the two models. It is difficult to pinpoint exactly what makes models compatible or incompatible, but we can suggest the following: if there are significant differences among some of the

basic assumptions underlying the models (e.g., "pavement deterioration is a probabilistic phenomenon" versus "for all practical purposes, the condition of a section follows exactly some given curve"), they are probably incompatible. The best way of resolving this issue could be to develop one of the models with the specific objective of making it compatible with the other one.

8. A Possible Implementation

We will now suggest possible choices for the strategic and the tactical planning models and describe a way of interfacing them.

For the strategic planning problem, one could use the Arizona model [8,9] or any similar Markov decision process model, since they are aggregated models providing a fine global picture of network evolution through time.

Regarding the choice of the tactical planning model, one could simply settle for some disaggregated analog of the first model selected. This would mean using a stochastic dynamic programming in which condition states for individual pavements and transition probabilities would be defined as in the strategic planning model. It is important to note that cost interactions could be included in this model, because pavement sections are considered individually. For any practical district or region network size, it would be impossible to compute the exact optimal solution of this model. We could however use the following heuristic procedure: starting from the solution specified by the strategic planning model, one tries to improve the solution by exploiting possible economies of scale. This would best be done by using an interactive graphics procedure which would display on a terminal screen the current solution at all times. With such a procedure, it would also be very easy to modify the solution to fit any local constraint which might render the initial solution infeasible in practice.

To interface the strategic and the tactical planning model, one could proceed as follows:

1) for each condition state, compute the expected cost per period for a section in that condition state at the start of the planning horizon using the optimal solution of the strategic planning model;

2) repeat this procedure for any performance measure of interest;

3) compute expected costs and expected performance measure values for each of the regions (or districts) using the results of 1) and 2) and the number of pavement sections in each state at the start of the planning horizon;

4) input the results of step 3) as budgets and performance objectives for the region (or district) to the tactical planning model;

5) from the optimal strategy of the strategic planning model, extract the recommended treatment in period 1 of the horizon for each section of the region. This will be the initial solution for the heuristic procedure solving the tactical planning model.

We could try to further precise how these steps could be accomplished, but this would probably require a very lengthy discussion.

9. Conclusion

We have proposed a new way to approach the problem of optimal planning of maintenance and rehabilitation programming which seems very promising. At the current time, there exists no pavement management system developed according to this approach, but we intend to start working on one in the near future and hope that we will be able to report on the results obtained within a year or two.

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